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ART. XXVIII.—*On Indian Iron and Steel; in a Letter addressed to the Secretary to the Royal Asiatic Society of Great Britain and Ireland, by J. M. HEATH, Esq.*

(Read Feb. 16, 1839.)

IN the month of June, 1837, the Managing Directors of the Indian Iron and Steel Company received a letter from Robert Clerk, Esq., Secretary to the Madras Governor, forwarding a copy of your letter of the 17th of February, 1837, addressed to the Governor of Madras, requesting information on the subject of wootz*, or Indian steel: the purport of Mr. Clerk's letter was to ask us to furnish the information and specimens required by you, provided we could do so without inconvenience or detriment to our own interests.

At the time Mr. Clerk's letter was received, I was the only one of the Managing Directors who was in possession of sufficiently detailed information on the subject of the manufacture of Indian steel, to be able to reply to the queries contained in your letter, but as the duties I had to discharge at that time in the superintendence of our iron works at Porto Novo, were exceedingly laborious, it was altogether out of my power to turn my attention to the subject previously to my departure from India, in November, 1837: the leisure afforded by the voyage home has enabled me to resume the subject of your letter, and I have now the pleasure to communicate to you such information on the subject of Indian steel, as my experience has enabled me to collect.

The ore from which the wootz steel is made, is the magnetic oxide of iron, combined with quartz, of which specimens accompany this letter: the ore varies much in its appearance, according as the grains of quartz and oxide of iron are large or small, but the proportion in which the component parts unite, is nearly uniformly 48 of quartz and 52 of oxide of iron, in 100 parts by weight.

It is found in many parts of the South of India, but the district of Salem is the principal seat of the steel manufacture. The ore occurs generally in the form of low hills, and the quantity of it which is exposed above the surface of the surrounding country, is so considerable, that it is not probable that it will ever become neces-

* Wootz, or Oots, is probably the name of steel in the Guzeratte language in use at Bombay, from which place the first specimens of Indian steel were sent to England under that name.

sary to have recourse to under-ground operations, supposing the smelting of iron ore from this district to be carried on to any extent that can be contemplated.

It is prepared for being smelted by stamping and separating the quartz from it, either by washing it in a current of water, or by winnowing it in the manner in which rice is separated from the husk : in most of the deposits of ore, parts are found in which the quartz is in a state of disintegration, and these, from the greater facility with which they are broken, are always selected by the natives for their furnaces.

The furnace, or bloomery, in which the ore is smelted, is from three to five feet high from the surface of the ground, and the ground is hollowed out beneath it to the depth of from eight inches to a foot : it is somewhat pear-shaped, being about two feet in diameter at the ground, tapering to about one foot diameter at the top : it is built entirely of clay, two men can finish one in a few hours, and it is ready for use next day. The blast is supplied by two bellows, each made of a single goat's skin, with a bamboo nozzle : the two nozzles meet in a clay pipe, which passes about half-way through the furnace at the level of the ground, and by working the bellows alternately, a tolerably uniform blast is kept up ; a semicircular opening, about a foot high and a foot in diameter at the bottom, is left in the furnace, and before each smelting, it is built up with clay. The furnace is then filled up with charcoal, and a lighted coal being introduced before the bellows, the fuel in the interior is soon kindled : as soon as this is accomplished, a small portion of the ore previously moistened with water, to prevent it from running through the charcoal, but without any description of flux, is laid on the top of the fuel, and charcoal is thrown over it to fill up the furnace : in this manner ore and fuel are added, and the bellows plied for four hours or thereabouts, when the process is stopped ; and the temporary wall in front of the furnace having been broken down, the bloom is removed by a pair of tongs from the bottom of the furnace : it is then beaten with a wooden mallet to separate as much of the vitrified oxide of iron as possible, and while still red hot, it is cut through the middle with a hatchet, in order to show the quality of the interior of the mass : in this state it is sold to the blacksmiths, who perform all the subsequent operations of forging it into bars and making it into steel.

The process of forging the iron into bars is performed by sinking the blooms in a small charcoal furnace, and by repeated heatings and hammerings, to free it as much as possible from the vitrified

and unreduced oxide of iron : it is thus formed into small bars about a foot long, an inch and half broad, and about half an inch thick ; in this state the iron is full of cracks and exceedingly red short ; and were an English manufacturer of steel to be told that cast-steel of excellent quality could be made from such iron, he would treat the assertion with great contempt.

It is from this unpromising material, however, that the Indian steel is always made ; the bars of iron just described, are cut into small pieces to enable them to pack close in the crucible : a quantity of these pieces amounting to about half a pound, and from that to two pounds, as the mass of steel is required to be of greater or less weight, is then put into a crucible alone, with a tenth part by weight of dried wood chopped small, and the iron and wood are then covered over with one or two green leaves ; the mouth of the crucible is then filled up by a handful of tempered clay, which is rammed in so close as to exclude the air perfectly.

The wood which is always selected to furnish carbon to the iron, is the *Cassia auriculata*, and the leaf used to cover the iron and wood is that of the *Asclepias gigantea*, or, where that is not to be had, that of the *Convolvulus laurifolius*. As soon as the clay, used to stop the mouths of the crucibles, is dry, they are built up in the form of an arch, with their bottoms inwards, in a small furnace urged by two goat-skin bellows ; charcoal is heaped up over them, and the blast kept up without intermission for about two hours and a-half, when it is stopped, and the process is considered complete : the furnace contains from twenty to twenty-four crucibles.

The crucibles are next removed from the furnace, and allowed to cool ; they are then broken, and the steel which has been left to solidify is taken out in a cake, having the form of the bottom of the crucible ; each cake is the produce of one crucible, and the steel is never procured from a larger quantity. When the fusion has been perfect, the top of the cake is covered with striæ, radiating from the centre, but without any holes or rough projections on it ; when the fusion has been less perfect, the surface of the cake has a honey-combed appearance, caused probably by particles of scorïæ and unreduced oxide in the bar-iron, and often contains projecting lumps of iron still in the malleable state.

The crucibles are formed of a red loam, which is very refractory, mixed with a large quantity of charred husk of rice ; they are made by taking a lump of the tempered clay in one hand, and giving it a rotatory motion, while it is hollowed out by the fingers of the other hand : each crucible serves only for one operation.

The natives prepare the cakes of steel for being drawn into bars by annealing them for several hours in a charcoal fire, actuated by bellows, the current of air from which is made to play upon the cakes while turned over before it at a heat just short of that sufficient to melt them. It appears from this, that in order to insure the fusion of the contents of the crucible, it is found necessary to employ a larger dose of carbon than is required to form the hardest steel, and that this excess is afterwards got rid of by annealing the cakes before a current of air at a high heat, the oxygen of the air combining with and carrying off the excess of carbon in the gaseous form: without this operation none of the cakes would stand drawing into bars without breaking.

The only fuel employed by the natives of India throughout the different stages of iron and steel making is wood charcoal. The magnetic oxide of iron, when separated from the quartz with which it is naturally combined in the ore from which the wootz steel is made, consists of 72 per cent. of iron and 28 of oxygen. The native method of smelting the ore is so exceedingly imperfect, that the produce from their furnaces in bar-iron does not average more than fifteen per cent.

When specimens of Indian steel were first examined by chemists in England, they were quite unable to discover the process by which it had been manufactured. The late Dr Pearson published an account of his examination of this substance in the seventeenth volume of the *Philosophical Transactions*, and the result of his observations is in these words: "We may without risk conclude that it is made directly from the ore, and consequently that it has never been in the state of wrought-iron." Dr. Buchanan's *Travels in the South of India* were published in the year 1807: they contain a very minute and correct account of the native processes of smelting iron and making it unto steel, illustrated by engravings. Dr. Heyne's *Tracts on India*, were published in 1814, and they also contain an account of both processes, along with a very interesting letter from the late Mr. Stoddart upon the quality of Indian steel, which he pronounces to be decidedly superior to any other description of steel; yet in page 223, of the first volume of the *Treatise on Metals*, lately published, it is stated, "that the wootz of India, in the state in which we receive it, is the immediate product of the ore, seems to be undoubted."

The principle of the Indian process is so different from that practised in England for making cast-steel, that it is not surprising that in the absence of all information upon the subject, Dr. Pearson

should have formed an erroneous opinion as to its nature. It has always appeared to me one of the most astonishing facts in the history of the arts, that the Hindús should be in possession of a process, the theory of which is extremely recondite, and in the discovery of which, there seems so little room for the agency of chance : it is impossible to suppose, however, that the process was discovered by any scientific induction, for the theory of it can only be explained by the lights of modern chemistry : in fact, all speculation upon the origin of the discovery seems useless. It appears an easy matter to trace the successive steps of the steel manufacture in Europe. In Europe, steel seems first to have been made in modern times in Germany ; the process consisted in partially decarbonating cast-iron in a finery, and bringing the metal under the hammer before the process for converting it into malleable iron was completed : this was, of course, the work of chance, as was also the further discovery that the iron manufactured from some kinds of iron ore, was fitter for making this natural steel, as it is called, than that made from other ore : this was for a long time the only description of steel made in Europe, and although the manufacture of cutlery has been established in England for some centuries, yet the only steel used for this purpose, for a very long period, was the natural steel of Germany.

As soon as chemical investigation had discovered that steel consisted of pure iron united to a very small proportion of carbon, an obvious experiment would be to endeavour to form steel by synthesis ; and hence the process of subjecting pure malleable iron to a high heat in contact with carbon, producing blistered steel as the result. This step in the manufacture was found to be a great improvement upon the German steel, and the next step which would immediately suggest itself, that of welding several bars of blistered steel together, and drawing them down into a single bar under a very heavy hammer, forming what is called shear-steel, was found still further to improve the quality ; still it was found that all these descriptions of steel possessed defects which rendered them unfit for purposes which required a high polish and a fine and strong edge : these defects could evidently be traced to impurities in the body of the steel, or variations in its quality ; and it would seem an obvious suggestion to endeavour to equalize the quality of the steel by reducing it to the fluid state in a close vessel, so as to prevent the dissipation of its carbon by exposure to the air at a high temperature. This is, in fact, the process now followed in England for making cast-steel, which is the only description of steel fit for fine cutlery ;

and simple and inartificial as the process appears, it was only discovered in England about the middle of the last century.

The antiquity of the Indian process is no less astonishing than its ingenuity. We can hardly doubt that the tools with which the Egyptians covered their obelisks and temples of porphyry and syenite with hieroglyphics were made of Indian steel. There is no evidence to shew that any of the nations of antiquity besides the Hindûs were acquainted with the art of making steel. The notices which occur in the Greek and Latin writers on this subject serve only to betray their ignorance of it: they were acquainted with the qualities and familiar with the use of steel, but they appear to have been altogether ignorant of the mode in which it was prepared from iron. The arms and cutting instruments of the ancients were all formed of alloys of copper and tin, and we are certain that tools of such an alloy could not have been employed in sculpturing porphyry and syenite.

Had the ancient nations of the west been in possession of the process of converting iron into steel, there can be no doubt that they would have used it in the fabrication of their arms, for in all parts of the world where steel is made, it can be sold much cheaper than copper. The price of steel in India is about one-fifth of the price of copper, but the expense of transporting it from India to Europe and Egypt by the ancient routes of commerce would have enhanced its price so much as to restrict the use of it to such articles as required to be possessed of a degree of hardness which could not be imparted to any other metal. One certain fact has reached us regarding the antiquity of the steel manufacture in India: Quintus Curtius mentions that a present of steel was made to Alexander of Macedon, by Porus, an Indian chief, whose country he had invaded. We can hardly believe that a matter of about thirty pounds weight of steel would have been considered a present worthy the acceptance of the conqueror of the world, had the manufacture of that substance been practised by any of the nations of the West in the days of Alexander. We may judge from the extent of the present, how much the cost of the article had been enhanced by transport from the place of its manufacture to the country of Porus.

We know that a maritime intercourse was maintained from the remotest antiquity between the Malabar coast, the Persian Gulf, the country about the mouths of the Indus and the Red Sea; and it appears reasonable to conclude that the steel of the South of India found its way by these routes to the country of Porus, to the nations of Europe, and to Egypt.

It appears then that the claim of India to a discovery which has exercised more influence on the arts conducive to civilization and manufacturing industry, than any other within the whole range of human inventions, is altogether unquestionable. What a theme for a reflective mind is the consideration of what would have been the social condition of the human race had the art of converting iron into steel still remained undiscovered !

A few remarks seem called for, regarding the distinguishing peculiarity of the Indian process of steel-making.

It will have been observed that it differs from the ordinary English process, from the circumstance of the iron being put into the crucible in the pure state, and without having gone through the process of cementation or conversion into blistered steel.

That iron could be converted into cast-steel by fusing it in a close vessel in contact with carbon, was a discovery made by Mr. D. Mushet about the year 1800. This was undoubtedly the original idea of a man of talent, following the light thrown on the theory of steel-making by the discoveries of modern chemistry. The substances Mr. Mushet proposed to use, were "charcoal-dust, pitcoal-dust, plumbago, or any substance containing the coaly or carbonaceous principle." Now this specification unquestionably comprises the principle of the Indian process, which adopts the use of dry wood, which is a "substance containing the coaly or carbonaceous principle." I believe, however, that Mr. Mushet*, in practice, confined himself to the use of charcoal-powder in preference to dry wood, in consequence of the comparatively small bulk of the former required to carbonate the iron, and the consequent saving of space in the crucible.

In the year 1825, Mr. Charles Mackintosh† took out a patent for converting iron into steel by exposing it to the action of carburretted-hydrogen gas in a close vessel, at a very high temperature, by which means the process of conversion is completed in a few hours, while by the old method it was the work of from fourteen to twenty days.

* Mr. Mushet took out a patent for this process, but, owing to causes entirely unconnected with the merits of the discovery, it was never successfully carried into practice.

† The patentee of the Indian-rubber waterproof fabrics. Mr. Mackintosh also took out a patent for his process for steel-making ; but although I have seen samples of the steel made in this way, yet the process was not found to answer on a large scale : it was found impossible to keep the chambers in which the bars of iron were suspended air-tight at the very high temperature to which it was necessary to raise them in order to enable the iron to combine with the gaseous carbon.

Now it appears to me that the Indian process combines the principles of both the above described methods : on elevating the temperature of the crucible containing pure iron and dry wood and green leaves, an abundant evolution of carburetted hydrogen gas would take place from the vegetable matter, and as its escape would be prevented by the luting at the mouth of the crucible, it would be retained in contact with the iron, which, at a high temperature, appears from Mr. Mackintosh's process to have a much greater affinity for gaseous than for concrete carbon ; this would greatly shorten the operation, and probably at a much lower temperature than were the iron in contact with charcoal powder. In no other way can I account for the fact that iron is converted into cast-steel by the natives of India in two hours and a half, with an application of heat, that, in this country, would be considered quite inadequate to produce such an effect, while at Sheffield it requires at least four hours to melt blistered steel in wind furnaces of the best construction, although the crucibles, in which the steel is melted, are at a white heat when the metal is put into them, and in the Indian process, the crucibles are put into the furnace quite cold.

I do not believe that the Indian process exercises any influence upon the quality of the steel ; its only advantage appears to be that it enables the Hindú to accomplish an object with the very imperfect means of applying heat within his reach, which it would be altogether hopeless for him to attempt, were he to imitate the steps of the European process.

It seems probable that the selection of particular kinds of vegetable matter to afford carbon to the iron, may not be altogether a matter of fancy. The Indian steel-maker of course knows nothing of the theory of his operations: he is satisfied with knowing that he can convert iron into steel by fusing it with what he calls " medicine," and this medicine experience has taught him must be dried wood and green leaves ; and as different woods and leaves very probably contain carburetted hydrogen in very different proportions, experience may have taught the Hindoo that he can make iron pass into the state of steel more quickly and with a smaller bulk of particular kinds of vegetable matter, than with others. The *Cassia auriculata* is the only wood I have ever seen used for the purpose ; it contains a large quantity of the extract called catechu : the leaf of the *asclepias* contains an acrid milky juice : the leaf of the *convulvulus* is in no respect remarkable.
